Natural Gas: a Long Modern Survey

Ferdinand E. Banks[♦]

Abstract

By "modern" survey I mean a survey that presents items and issues with which readers should be familiar, but for one reason or another are often unaware. This is important because, according to Daniel Yergin of Cambridge Energy Research, the biggest challenge facing the U.S. energy sector today is ensuring the availability of sufficient gas supplies.
I can add that what we should avoid at all costs is an unexpected peaking of e.g. global oil and gas production, which could not only lead to economic and political chaos, but even to wars as major consuming countries elect to employ their military assets to obtain a satisfactory share of remaining resources. I attempt in this paper to correct and update the discussions in my book on natural gas (1987), as well extend the chapters on gas in my two energy economics textbooks (2000, 2007); and I also hope to provide readers who absorb a large part of the exposition with a 'competitive advantage' in their interaction with teachers, students, colleagues and/or adversaries. Unfortunately the inclusion of some mathematics in this contribution could not be avoided for pedagogical reasons, although some of it can be easily bypassed.

Keywords: *Reserve-production ratio, Russian gas, gas deregulation, gas pipelines.*

Introduction

In many respects, natural gas is an ideal fuel. Its environmental qualities (in terms of its emissions of 'greenhouse' gases) are helping to make it the most demanded of the fossil fuels (i.e. gas, oil and coal), and there is a great deal of it in the crust of the earth – though not as much as many observers believe. As pointed out by Ken Chew (2003), the *amount* of gas resources discovered annually peaked in the beginning of the l970s, and the *number* of discoveries early in the l980s. (This lends weight to a contention by Julian Darley (2004) that gas production could 'plateau' before 2025.) Natural gas is found in appreciable quantities in very many countries, and Russia has the world's largest reserves and is the biggest producer.

[♦] Professor, Nationalekonomiska Institutionen, The University of Uppsala, Uppsala Sweden. The School of Engineering, Asian Institute of Technology, Bangkok Thailand.

The United States (U.S.) is the largest consumer, and although it has about 3% of world reserves, Europe (excluding Russia and Eurasia) consumes roughly 20% of global output. Considerable gas has attained the status of '*stranded gas'*, which means gas that has been discovered but is not economically viable for physical or economic reasons: for instance, it is too far from main pipeline routes, or localities where gas consumption is high, to make its exploitation attractive.

Since l980 natural gas has exhibited the fastest consumption growth of all fossil fuels – averaging between 2.5 percent per year (= 2.5%/y) and 3%/y. Only primary electricity exceeded this figure over the same period, averaging almost 4%/y. (Primary energy is energy obtained from the *direct* burning of coal, gas, oil, etc, as well as electricity having a hydro or nuclear origin. Electricity obtained from e.g. a gas turbine is a secondary energy resource.) The average energy content of natural gas varies from a low of 845 British Thermal Units per cubic foot (845 Btu/cf = 845 Btu/ft^3) in Holland to 1300 Btu/ft^3 in Ecuador. In Russia it averages 1009 Btu/ft^3 and in the United States (U.S.) 1025 Btu/ft^3. In this article, as in my textbooks, I follow the usual practice of rounding these numbers to 1000 Btu/ft^3: this is a number that students of energy economics should *always* have at their finger tips, and it is more important than the equivalent amount in Btu/cubic meter (= 28.6 Btu/m^3). You should also note the difference between *energy* – which above is in Btu – and *power*, which is relevant later in the discussion of compressors for pipelines, where it is measured in horsepower.

North America (including Mexico) has about 5.1% of world gas reserves, with the United States (U.S,) holding the largest part. South America has about 4.8%, with Venezuela being the largest possessor. Western Europe about 3%, and surprisingly The Netherlands has more than the UK (48 trillion ft^3 (= 48 Tft^3) versus 17 Tft^3 , but much less than Norway (102 Tft^3). However even so, because of its location and storage facilities, The Netherlands is regarded as the *swing producer* for the Western European gas market, which implies that if there were a sudden decline in the physical availability of gas , that country could (and ostensibly would) fill the gap – which may or may not be true. Saudi Arabia has been pictured as playing this role for the world oil market, however with the rapid increase in the global consumption of oil, it may not be able to perform this function much longer – even if it wanted to. Global reserves are approximately 6405 Tft^3, and production about 2865 billion cubic meters (= 2865 bcm).

Eurasia (= Russia, Ukraine and Central Asia) has about 36% of global reserves, with Russia, the gas superpower, in possession of 85% of these. An important observation that can be offered here is that the extensive deregulation of gas that is scheduled to take place in the European Union (EU) may result in greatly increasing the *market power* – i.e. the *monopoly* or oligopoly power – of Russian gas exporters. The sponsors of this deregulation are apparently unfamiliar with the economic logic supporting this uncomfortable prospect, and so it might be suitable to point out that collusion on the buying side of the *wholesale* gas market (which is where large buyers obtain gas from external producers), together with continued regulation on the selling side of the *retail* market (which involves final consumers), could optimize the welfare of Western European firms and households who are becoming increasingly dependent on foreign resources This is because the bargaining power of the aggregate of large buyers might be increased. Decision makers in the gas importing countries should attempt to understand this situation, because important forecasting establishments claim that with global gas demand scheduled to almost double by 2025, gas prices could escalate.

The Middle East has about 36% of global reserves, with Iran possessing almost 50% of this amount, but Qatar is the most important exporter of gas in this region, and has become the leading global supplier of liquefied natural gas (LNG). Africa has 7%, with most of it in

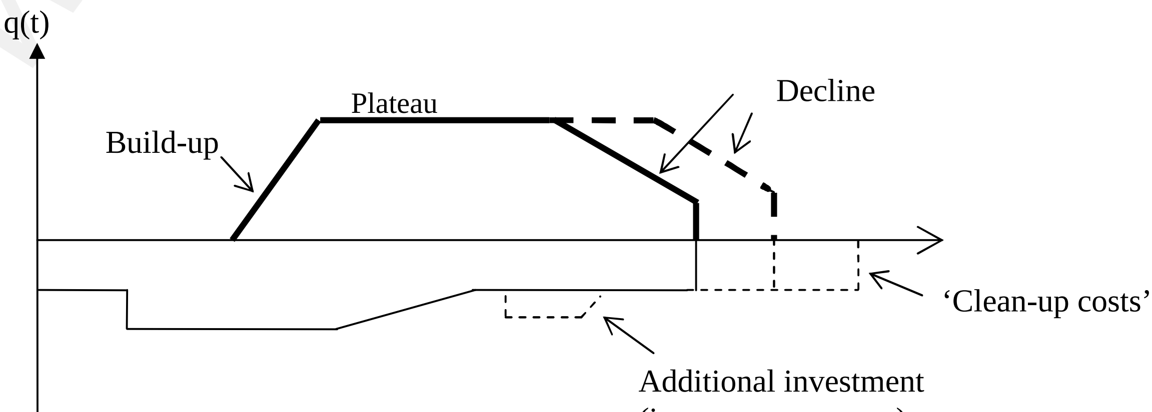
Nigeria and Algeria; and there is slightly more than 8% in Asia and Oceania, with Australia, Indonesia and Malaysia being the main players. As is the case with oil, China is going to require an enormous amount of gas, and perhaps more than is or will become available from its present key suppliers, Australia and Indonesia. The U.S. remains the world's largest gas market, but Japan is the largest importer of LNG, and enjoys the considerable advantages that come with being able to exercise market power – in this case *monopsony* – when confronted by its present suppliers.

Altogether there are approximately 6405 trillion cubic feet (or 224 trillion cubic meters) of proved reserves in the world, but appearances sometimes deceive. The United States cannot be regarded as particularly favoured any longer where gas is concerned, given the forecasts of its huge future consumption. It also appears that the U.S. does not produce much more gas today than was produced 30 years ago. In addition, the reliance of that country on suppliers outside North America (and Mexico) steadily increases. These suppliers include distant countries that at the present time are able to ship only limited quantities of liquefied natural gas (LNG) to North America, and in addition a shortage of existing and planned terminals for receiving more gas is evident.

Another country that might be moving into an unfavourable gas position is the United Kingdom (UK), where oil production recently peaked, and domestic gas reserves will soon be unable to support expected consumption. There is an important lesson here. As in California, a very large inventory of gas-based facilities came into existence because of technical improvements in gas burning equipment and low gas prices; while later (for a while) it appeared that it was more economical to pay higher prices for gas than to invest in alternative sources of energy. Thus we have another predicament in which, *in the presence of uncertainty*, we see the advantages of sometimes having a highly diverse portfolio of assets – e.g. gas, coal, nuclear, renewables – instead of "falling in love" with a single energy medium, as pointed out once in *Forbes*.

One purpose of this paper is to clarify important issues that have not been adequately treated in much of the literature. For example, theories about the abundance of natural gas are often based on the observed size of the existing reserve-production ratio (= Q/q ratio), where Q is units of reserves, and q is output per year. For gas, this ratio was about 63 (years) at the beginning of 2007, implying that even if no more gas is discovered, current production can be maintained for more than 6 decades. (Similar thoughts prevail for oil, whose global Q/q ratio is close to 40.) Most geologists – though not most economists – understand the futility of this approach, because *prima facie* it suggests that current production could be maintained for Q/q years, and then terminated almost immediately. It also fails to stress the possibility of a comparatively early peaking of output, as well as the economic logic underlying this phenomenon for both gas and oil.

When we examine production profiles in major oil or gas region in e.g. the United States, what we see is a rising output (or build-up for oil and gas) that eventually peaks, perhaps forms a plateau, and eventually begins to decline, even though there may still be a huge amount of the resource in the ground. As shown in Figure 1, there is a decline with or without additional investment designed to extend the life of the structure. *The reason (and perhaps the only reason) is that on the basis of reserves that have been identified in a particular deposit of field, it is uneconomical to attempt to prolong the plateau indefinitely*!



If the explanation for this configuration turns on economics and not geology, an explanation is due. Let's start with the following equation, which has to do with the maximization of *discounted* profits (= *discounted* Revenue minus Cost) over N periods.

$$V = \sum_{t=0}^{N} (p_t q_t - c_t q_q)(1+r)^{-t} + \lambda [Q - \sum_{t=0}^{N} q_t] \qquad \textbf{(1)}$$

In the first parenthesis we have *expected* profits in period 't', or expected revenue ($R_t = p_t q_t$) minus expected cost ($C_t = c_t q_t$), while in the third parenthesis we have the *predicted* amount of the resource (e.g. gas), Q, that will be distributed in an *optimal* manner over N periods ($q_1 + q_2 + \ldots + q_N \leq Q$). The second parenthesis, $(1+r)^{-t}$, merely discounts the profit in period 't': profits in distant periods have less value than those of e.g. today. It might also be useful to know that $\Sigma\ (R_t - C_t)/(1+r)^t$ is sometimes called the capital value of future receipts: it is the current price of the rights to a stream of future – or *expected* future – receipts. In conventional presentations N is taken as given, and 'c' is usually regarded as a constant that is equal to both average and marginal cost for the N periods. The implicit assumption here is that prices and costs, as well as the amount of the resource, are correctly forecast at the beginning of the current period. λ is a Lagrangian multiplier, and gives us the scarcity value of the resource: e.g. it is zero if R exceeds the amount of the resource expected to be extracted during the N periods (because then the resource is not scarce).

In these circumstances, if we differentiate V with respect to the values of q, and manipulate slightly, we obtain the famous Hotelling (1931) expression $\Delta p/p = r$, where p here is defined as the 'net' price – or price minus the marginal cost – and this net price increases at the rate r. *In terms of the real world, where the ex-post (i.e. after the fact) production curves of gas take on the appearance of the curve in Figure 1 (or even a distinct 'bell' or 'normal' appearance), this is a nonsense result*! In order to obtain something approximating realistic production curves, it is necessary to assume that 'c' can increase as time passes and the deposit is gradually exhausted. This is because the most important variable for an individual deposit is NOT 'r' – which your favourite economics teacher might told you – but *deposit pressure* and its significance for the cost of extraction. As gas is removed and deposit pressure falls, it may be necessary to introduce additional wells or pressure augmenting activities in order to maintain output. If you saw the film '*Five Easy Pieces*', the good Jack Nicholson was apparently occupied with work that was intended to compensate for the decline of an oil deposit. Had it been gas instead of oil, the same observation is valid.

For students of energy economics, the basic issue here can be shown with a simple equation. In my lectures I sometimes use $C = \alpha x / (\beta - x)$, where C is the cost (in some monetary unit) of removing x percent of a deposit, and α and β are constants. If for example β was equal to 100, then C approaches infinity when the deposit approaches exhaustion. At this point readers might substitute a few values of x in the equation in order to see what happens to C, however it is just as simple to look at a couple of derivatives: $dC/dx = \alpha\beta/(\beta - x)^2$ and $d^2/dx^2 = 2\alpha\beta/(\beta - x)^3$. Both are positive, and so not only does cost increase as more of the deposit is removed, but this increase 'accelerates'.

In considering the present topic, it is also essential to be aware of something called the 'natural decline rate', which involves the 'deterioration' of a deposit due to previous production, but like deposit pressure does not explicitly enter into the above expression. Before saying something about the decline rate however, it should be noted that the same kind of production pattern illustrated above will likely be duplicated on a global scale, and unfortunately sooner than many readers of this paper expect. On the basis of present supply-demand trends, it is possible, though not certain, that in 20-25 years the output of gas will peak, and after a short or long *plateau*, begin to decrease. It has been suggested that the bad news about gas will not take a minimum of 20 years to appear, as the former Chairman of the Federal Reserve System Alan Greenspan flatly stated in his testimony before the Committee on Energy and Commerce of the United States House of Representatives in June, 2003. On that occasion the Chairman was not thinking of in terms of depletion but of price, and he had good reason for his concern.

The least complicated equation for discussing this matter is probably the one given directly below, where we are discussing a case that in economic theory is called 'depreciation by evaporation', and in which an asset is subject to a constant force of mortality 'Θ'. The relevant equation takes on the following appearance.

$$\Lambda = A \int_{t}^{t+T} e^{-(\Theta + r)(\tau - t)} d\tau = \frac{A}{\theta + r}\left[1 - e^{-(\Theta + r)T}\right] \qquad (2)$$

In this expression A is the amount of the asset, and r is a discount rate. It would be a simple matter to make 'Θ' a function of the 'deterioration' of the asset.

Equations (1) and (2) could possibly serve as a starting point for a comprehensive exposition if some readers were not allergic to integrals, but in any case the important thing is an interpretation of (2). What this expression says is that the presence of a natural decline reduces the value (Λ) of the deposit. More important, the mere fact of depreciation means that output can only be maintained as a result of investment, and as alluded to earlier, in the long run investment might become too expensive. This theme can be approached without calculus, but even so requires too extensive a discussion of the economics for this rudimentary presentation. It might be useful to suggest though that an implicit investment function with investment designated as I and revenues R (=pq) obtained from investment might serve as the starting point for this exposition. With reference to e.g. Figure 1, that function would take on the appearance $\psi(I_1, I_2, \ldots, I_T; R_2, R_3 \ldots, R_{T+1})$ for periods '1' to e.g. 'T+1'.

Next we should carefully note that 1000 cubic feet (or 28.6 cubic meters) of gas has an average heating value of approximately 1,000,000 British Thermal Units (= 1 mBtu). (The exact figure, as noted earlier, may be as much as ten percent higher or lower.) One barrel of oil has an average heating value of 5,800,000 Btu. Only a few years ago OPEC still expressed its intentions to keep the world oil price between \$22 and \$28 per barrel (=\$/b) if possible, and so we can immediately calculate that this corresponds to a gas price of \$3.8/mBtu to

$4.8/mBtu, where 'm' signifies million. Something of interest here is that long before the oil price began its present ascent, there was an occasion when the gas price in the US spiked to $10/mBtu (= $58/b in oil terms), and a similar phenomenon was observed in Mexico. Numbers like these concentrated more than a few minds at the upper political levels in the energy intensive countries, but worse may be in store, since the OPEC countries may have come to the conclusion that $70/b is the lowest price at which they should sell oil. This corresponds to an 'oil equivalent' price for gas of $12/mBty. In the third section of this paper I examine price formation in the natural gas market, and touch on this subject once more.

It seems likely that just about everybody interested in energy has heard gas referred to as the 'fuel of the future'. In fact I used this expression several times in my first energy economics textbook (2000). But although I emphasized gas' *relatively* favourable environmental properties, it should not be forgotten that gas also emits a sizable quantity of carbon dioxide (CO_2), and its high methane content makes it less attractive than often portrayed to TV audiences.

Readers should also *never* lose sight of the fact that, despite the growing important of gas, in terms of physical fundamentals oil is still the most valuable energy resource. For instance, as energy resources must be moved over longer and longer distances from large suppliers to large buyers, gas' relatively inferiority to oil increases. Whether by pipeline or tanker, the unit transport costs of oil are lower than those of gas. If we consider a given volume of pipe, oil contains (on the average) 15 times as much energy as gas, which immediately reflects – negatively – on pipeline investment costs for gas. Furthermore, when considering intercontinental trade, transporting gas by ship over all except very long distances is more expensive than by pipeline, while transporting oil by tanker over the same distances is less expensive than by pipeline. This is one of the reasons why, quantitatively, the kind of global competitive market that various observers hope or expect will come into existence after enormously expensive LNG investments are carried out, may prove to be disappointing.

As with oil, there are plenty of energy professionals ready to claim that technological advances will ensure that we will always be able to obtain the gas and other energy resources we need at prices that we can afford. The technology booster club is now turning its attention toward innovations that might make it possible to exploit vast deposits of crystallized natural gas suspended in Arctic ice, or buried just below the ocean floor, and which are known as methane hydrate. Optimists even claim that it is now possible to obtain controlled volumes of methane from a hydrate-rich area in North Canada, and apparently some or all of this hydrate-based gas has been officially classified a viable energy reserve.

Similar extravagant claims are being advanced about a big slice of the oil in Alberta that is extracted from tar sands, and which in theory is capable of making Canada an oil producer of the Gulf format. In truth only the richest of these resources are worth exploiting until oil and gas prices escalate even more, and then the laws of thermodynamics may stand in the way of making energy dreams come true. The problem seems to be that it may take more energy to exploit these 'unconventional' resources than they contain, and much of this energy might have to come from expensive natural gas – although I have occasionally argued in my lectures that under certain circumstances this trade-off is acceptable. If, for example, an inexpensive energy source could be transformed into expensive synthetic oil, then thermodynamic considerations may not be so important in the short run. According to official forecasts, it will not be before 2020 that Canadian tar sands can provide a modest 4mb/d of oil.

Some Aspects of Economic Theory and Gas Pipelines

There is always a problem in a presentation of this nature concerning the choice of topics to be reviewed. In my first energy economics textbook I had a fairly long discussion of gas pipelines, while in the latest textbook – which is designed to be an introductory textbook – this topic was only treated *en passant.* As I found out in my lectures in Bangkok, some students wanted more attention paid to gas pipelines, and so what I shall do now is to extend the discussion in my earlier textbook. Readers who want a very thorough exposition of the *economics* of gas pipelines should examine the work of the late Hollis Chenery (1949, 1952). Let me emphasize though that what is taking place below is to obtain a production relationship that can provide *optimal* values of the inputs with a given amount of gas to be transported a certain distance.

Perhaps the best way to begin the exposition is with a diagram showing some of the elements in a typical pipeline. This is presented below.

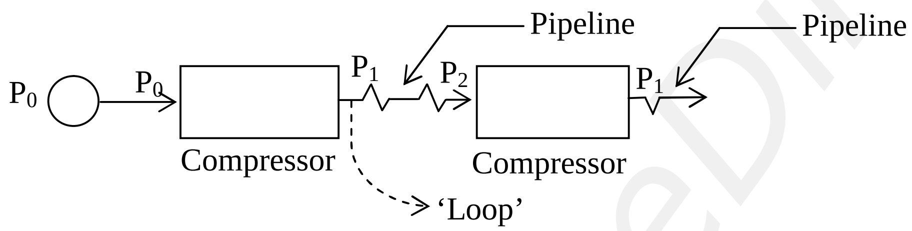


Figure 2

As we should note from this diagram, a gas pipeline is a fairly complicated structure. There will be considerable algebra in this section, but before we come to that it seems appropriate to peruse certain important concepts. To begin, readers should understand the expression *sunk costs*. Sunk costs are expenditures that, once made, cannot be recovered: they are associated with decisions that cannot be reversed later. A pipeline that costs billions of dollars can be chopped up and sold to scrap dealers for thousands or a few millions, but conceptually it seems appropriate to regard the main gas transmission lines as sunk investments. (On the other hand, a *fixed cost* is a cost that is fixed in the short run. A 'crack house' can be renovated and turned into a luxurious town house – at least in theory.) The most important costs associated with a gas pipeline are planning and design, acquisition and clearing of right-of-way, construction and material costs (e.g. labor costs, the cost of pipes and compressors, etc), the cost of monitoring the pipeline and performing maintenance, and energy to power the compressors (which are analogous to pumps in an oil pipeline, in that they transfer mechanical energy from e.g. a motor to the gas that is to be transported).

The expected life of a gas pipeline can exceed 30 years, and the investment can be extremely large. Russia has promised to build two pipelines to China, and their cost is estimated at 10 billion dollars. Strictly speaking, a pipeline cost should be regarded as sunk, but for pedagogical reasons no distinction will be made between sunk and fixed costs, since in almost all economics textbooks the word "sunk" seldom appears in the chapters on production theory. On the other hand, the expression 'increasing returns to scale' is often used in discussions of the sort that will be carried out here, and so I want to present a simple example which applies to both oil and gas pipelines.

In designing a gas pipeline, engineers might think in terms of varying the pipeline diameter and the number and size of compressors, as well as things like the amount of maintenance that will be required. Increasing the size (and energy output) of a compressor, without changing the diameter, raises the speed at which the commodity goes through the line, and thus increases the '*throughput*' of a given size pipe. Similarly, increasing the diameter of a line with the compressor size constant, might also raise throughput, since there is less resistance to flow (per cubic feet of gas) in a larger pipeline. A fundamental issue here is how much of the commodity is in contact with the inside of the pipe, and not just the total volume of throughput.

By way of extending this simple observation, remember that the volume of a pipe of length L, with radius r, is $\pi r^2 L$. (For convenience, take L = 1 foot or 1 meter). The inside surface area of the same pipe is $2\pi r L$. If the radius is doubled the surface area is also doubled, *but the volume of the interior of the pipe is increased by a factor of four*! Furthermore, a small amount of algebra informs us that there is less surface area per unit of volume for larger diameter pipes than for pipes with a smaller diameter, and as a result there is less frictional resistance per unit of throughput for a larger than for a smaller pipe. Then why not increase the radius of the pipe indefinitely in order to exploit the returns to scale being described? The answer – as you discovered in Economics 101 – is that at some point it is less expensive to raise throughput by a marginal addition to compression than by increasing the pipe diameter. I can add that just as (*ceteris paribus*) we have returns to scale in the pipe, we might also have returns to scale in compression, at least up to a certain point. You can think about this prospect in terms of the 'soup-bowl' diagrams that you enjoyed sketching in your first course in economics, and which applied to many kinds of equipment.

It has been suggested that if a pipeline manager is in position to raise (transmission) prices after gas producers have made their drilling and development investments, it will cause risk averse gas producers to limit the size of their investments in order to avoid being unpleasantly surprised by an increased price of transmission. This reasoning also works in the other direction. If gas producers have several pipelines through which to transmit their output, it could place pipeline managers in a dilemma in that they would always face the threat of gas producers transferring their affections to another carrier. On the national level this suggests that an optimum arrangement might call for a single owner for gas deposits and pipelines. A similar provision 'might' be possible internationally, but this is less likely. Instead, the optimal solution probably turns out to be complicated but necessary long term contracts. Under no circumstances does it mean an enthusiastic resort to short term arrangements that the EU Energy Directorate is trying to promote except, possibly, in very special cases.

What is being said here is that firms to not want to find themselves in possession of a large amount of worthless capital equipment – e.g. equipment that becomes worthless because the demand for pipeline capacity or gas suddenly and drastically collapses. The algebra of this situation will be avoided because it involves some probability theory, however if a firm is risk averse and wants to avoid the financial dangers associated with excessive investment in fixed or sunk capital, then long term commitments make a great deal of economic sense. It is difficult for me to see how a rational person could come to any other conclusion.

In order to carry on an elementary but meaningful discussion of the *economics* of gas pipelines, it is useful to put the production relationship into the form of the kind of production function that you encountered in your introductory economics courses, where output is a recognizable function of inputs. In the present discussion there is no problem with output (i.e. gas), although inputs (pipe and compressor size/capacity) might require some thought. But before beginning this exercise, I want to present a simplified version of an article written by R.E. Hodges (1985), in which there were three engineering relationships having to do with natural gas that were developed by the American Petroleum Institute. Some readers might prefer this departure to systematically formulating an optimization problem of the kind presented in intermediate economic theory.

If we take the output of the pipeline given, and equal to q*, then Hodge's first equation was for the gas velocity in a pipeline at the output of a compressor, and this is taken as a function of pipe diameter (D), and pressure at the outlet (p_1). Implicitly this equation is V = V(D,p_1), with $\delta V/\delta D < 0$ and $\delta V/\delta p_1 > 0$: with a given exit pressure for a compressor, velocity decreases as the diameter increases; and with a given diameter velocity increases as exit pressure increases. If the equation for V was written in explicit form, it would contain a number of thermodynamical constants/parameters, and in the last equation below the allowable stress of the metal used in the pipeline is also included.

The next equation is for what Hodges calls a friction factor, and this can be written F = F(V,D). A high gas velocity and a large diameter mitigate pipe friction, and so we have $\delta F/\delta D < 0$ and $\delta F/\delta V < 0$; however we can get rid of the V by substituting from the first equation, which gives us F = F(p_1,D), which is very convenient. Finally, the (recommended) pressure decline in a (given) length of pipe (L) between compressor stations, and with given output q*, depends on p_1, D, and F, (as well as the aforementioned thermodynamical constants). This can be written $\Delta p = p_1 - p_2 = g(p_1, D, F)$, where length and output enter the equation as parameters. Since F is a function of p_1 and D however, we can again make a substitution and obtain $\Delta p = g(p_1, D)$, or $p_1 = p_2 + g(p_1, D)$. In the light of the discussion that will follow, p_1 can be considered a proxy for compression – i.e. the 'size' or rated capacity of the compressor (in horsepower). If we have the cost of pipe and the cost of compression, then by juggling these relations – probably with the help of a computer – we can obtain the optimal values of D and p_1, where optimal in this case means values that give us the lowest *total* cost.

In a similar vein, Chenery began his analysis by writing two equations for the system, with the first being an engineering relationship governing the flow of gas, or q = Kf(D, p_1, p_2). K is a constant covering a number of thermodynamical factors (such as temperatures and specific gravity of the gas), D is the diameter of the pipe, p_1 is the outlet pressure from a compressor, and p_2 the inlet pressure. These pressures are shown in Figure 2, and it might be useful here to give an example of the equation used by Chenery, which is $q = KD^{8/3}(p_1^2 - p_2^2)^{1/2} = KD^{8/3}p_1[1 - (p_2/p_1)^2]^{1/2.}$. A prominent shortcoming in this equation is that the distance between compressors (L) is not present, and this deficiency is not entirely ameliorated by Chenery's decision to standardize the distance to 100 miles. The thing to understand though is that Chenery was dealing in economics and not engineering, which provided him (and me) with a certain indulgence.

Considering the discussion of pipelines from Russia to Western Europe that took place at the Stockholm School of Economics recently, it became clear that the distance between compressors is an important variable, and in line with the work of Paulette (1968), it might be better to write the implicit relationship above as q = Kf(D, p_1 , p_2 ,L). Then, with q 'given', and some sophisticated (and perhaps computer aided) assumptions about the two pressures, it might be possible to solve for the optimal distance between compressors. However I am not sure that in the present discussion there is anything to be gained by questioning or extending the work of Chenery, who happens to be another of those persons who should have received a Nobel Prize in economics, but for reasons that cannot be discussed here, was ignored.

Chenery's second equation had to do with compression (H), measured in horsepower, and was $H = [k_1(p_2/p_1) - k_2]q$, In this discussion it will be kept in implicit form, beginning with H = h(q, p_1, p_2), and disregarding the parameters k_1 and k_2. The question thus becomes whether we have enough information to construct a conventional production function, or for that matter do we have too much. If our aim is to construct a conventional function such as q = f(H,D), then it appears that we have too much. After examining Figure 2 for instance, we can ask where does p_0 fit into the analysis, and here Chenery assumed that $p_0 = p_2$: gas comes from out of the ground under pressure p_0, and the compressors are supposed to return it to the value after the decline caused by its journey through a pipeline. This is a 'weighty' approximation.

At this point it might appear that p_1 should also appear in our production function, but among other things, if we desired to graph this expression we would have a problem. As it happens, Chenery relieves our anxiety by supplying an 'auxiliary' relationship that has to do with the highest allowable pressure in the pipe, which will be called p_1 in the sequel. This equation features the pipe thickness (T), the allowable working stress (S), which depends on the material used to construct the pipe, and the pipe diameter, and is $p_1 = 2ST/D$, which in implicit form is $p_1 = z(S,T,D)$.

Now let us put all of this together in order to arrive at $q = f(H,D)$. H is power (not energy), and is measured in horsepower. My assumption is that this horsepower can provide a given maximum outlet pressure for the compressor. Thus, on the vertical axis of a familiar isoquant diagram, each value of H corresponds to a certain *maximum* (achievable) pressure. Buying the compressor (i.e. obtaining this horsepower) involves periodic interest and amortisation costs, as well as the cost of the energy required to operate the compressor. These costs will be called of w_2 per period. (Usually the "period" is one year.) It should also be understood that if the energy driving the compressors is gas, then the q given here is a gross rather than a net amount. Next, given a diameter D, and a maximum outlet pressure, we can obtain a pipe thickness from Chenery's 'auxiliary' equation or a similar relationship. In a typical course in 'Strength of Materials' at a typical American engineering school, this is a simple operation, and so the cost of this thickness of pipe functions as a *proxy* for the cost of the diameter (which was determined by output pressure.. This cost can be called w_1. What we want to do now is to minimize the cost ($= w_1D + w_2H$), given a (gross) amount of output q^*. Normally we would have an explicit expression for $q(D,H)$, and we might carry out the optimisation procedure using a 'Lagrangian'. To be exact we have:

$$C^* = w_1D + w_2H + [q^* - q(D,H)] \qquad (3)$$

An exercise of this nature is dealt with in the book by Abraham and Thomas (1970) under the title "the minimum cost principle", however the necessary technique can be found in almost all of the intermediate economics books that are now available. In fact, with an explicit expression for $q(D,H)$, the optimal values of D and H (= D^* and H^*) can usually be easily solved for without a Lagrangian. Please remember though, that once we get q^*, if gas is used to provide energy for the compressors, the amount must be subtracted in order to obtain the net output: put another way, 'throughput' should be distinguished from capacity. As an exercise, readers with a background in economics should carry out the above optimization using an isoquant – isocost diagram based on a simple neo-classical production function (e.g. $q = q(D,H)$ might do).

It might be possible to obtain a more precise distinction between throughput and capacity employing the conservation of energy, but that is a complication that will be avoided in this paper. By way of contrast, some remarks about the "loop" in Figure 2 seems appropriate. This loop generally amounts to a parallel section of pipe that is sometimes added in order to increase capacity, since using a loop is often preferable to increasing the size of the pipe. Here I can use the discussion in my new textbook.

By supercharging the existing compressors, and/or adding compressors, it can become economical to add parallel sections to the existing pipeline. Note that this does not strictly mean duplication, since the cost-output relationship turns on the amount of supercharging or additional compression, the diameter of the pipe used for looping, and the construction expenses associated with the looped section. An interesting looping exercise was carried out on the Roma-Brisbane pipeline in Southern Queensland (Australia). Sections pipe were laid parallel to the main line, with a separation of 4-8 meters, and in this way capacity was doubled. The price of the gas being delivered increased, but this was not surprising since a price increase was necessary in order to justify initiating this particular looping project.

In theory, output expansion via looping can feature constant, increasing, or decreasing unit costs. Without going too deeply into the matter, it needs to be emphasized that when there are increasing returns to scale in both compression and transmission, which is likely, then neo-classical economics suggests that optimal behaviour calls for initiating (and in some cases completing) projects well ahead of the demand for new capacity. Among other things, if this is done it might be possible to avoid any (per unit) increasing costs associated with looping if it turns out that sizable increases in capacity are necessary at a later date.

Price Issues

The ability to substitute gas for oil is often recognized by indexing the price of gas to that of oil. This is to some extent an imperfect way to approach this issue because substituting gas for oil is not the same as substituting pepsi-cola for coca-cola. However it does imply a recognition of sorts that the 'Btu' price of oil and gas should not diverge by too large an amount. At the present time the average price of gas for North America and Western Europe is \$7/Btu, while the price of oil is approximately \$15/Btu. It has been suggested by the energy expert of an important business publication that this disparity cannot remain, and as a result the price of oil will fall. I prefer to believe that in the short or the long run this gap will be partially closed by a rise in the price of gas.

In any case, an elementary indexing formula that I presented in my earlier energy economics textbook for the price of gas at time 't' was:

$$P_{gt} = 3.65\ [\text{Average price of 5 crudes at time 't'}/27.444] \qquad (4)$$

In this expression 27.444 was the average dollar price of a barrel of crude oil (= \$27.444/b) at the time this particular contract was signed. The expression in the brackets is then multiplied by \$3.65/Mbtu, which was the chosen base price for gas. The 5 crudes are 'negotiated' by buyer and seller, and not chosen at random, and this process is probably more complex than meets the eye since more or fewer crudes could have been chosen, and different base prices specified. A more general indexing equation for gas was presented by Asche, Osmundsen and Tveterås (2000), which was:

$$P_{gt} = P_0 + \Sigma\alpha_j(P_{jt} - P_{j0})(EK_j)\,\lambda_j \qquad [\text{for } \forall \text{ j's}] \qquad (5)$$

The reference price is P_0. α_j is the weight that is given the substitute 'j', and we take $\Sigma\alpha_j = 1$. $(P_{jt} - P_{j0})$ is the price change for substitute 'j' from the base period to the relevant period 't', and EK_j is an energy conversion factor that takes into consideration the energy content of the substitute. Finally, λ_j is called an *impact factor* for price changes in substitute 'j'. This is also a kind of weight, and so perhaps we should have $\Sigma\,\lambda_j = 1$, where the summations (Σ) are over all of the values of 'j').

Indexing formulae of the type shown here are undoubtedly employed on long term contracts, although it probably often happens that the future price is simply fixed for a certain period of time via negotiations between buyer and seller, or tied to the spot price, and if market conditions change drastically, another round of negotiation takes place. At the same time there is a spot market which is utilized to a lesser or greater extent. In the case of oil it is clear to all viewers of CNN or Fox News that inventories (i.e. stocks) are the key factor determining the spot price, and inventories are undoubtedly of some importance in the case of gas, though not to the extent as oil.

In dealing with this matter I will employ the stock-flow model that I developed for discussing the short term price of minerals such as copper, aluminium, tin and zinc, as well as oil, although the basic insight into pricing in this type of market was supplied by Professor Franklin Fisher of MIT in his work on the copper market. A conventional representation is found in Figure 4, and the accompanying discussion there clarifies that generally the diagram applies to entire sector and not a single firm.

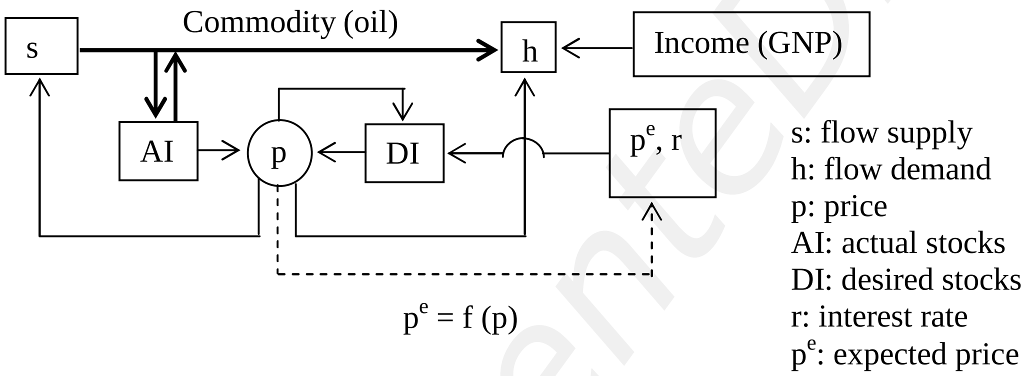


Figure 3

Even in elementary mathematical economics textbooks, as well as the almost nightly bad news about the oil price on TV infotainment, you have heard – perhaps without realizing it – some information which suggests the formulation of an equation in which the change of price with respect to time is a function of the difference between AI and DI, which means that the relevant model is a stock -flow model of the type in Figures 3 and 4, and not the flow model that you mastered in Economics 101. In the future these will be designated A and D, and at this point we can remember some advice of Professor Lipman Bers (1975), which is that the formulation of differential equations is what makes the world go round. The implicit form of the relevant equation for Figure 3 might be dp/dt = f(D – A), and I will claim here that this expression and the above diagram are the strongest parts of the present analysis. *Everything else is arbitrary*!

Now let's write the equation in a simple explicit form: dp/dt = – λ(A – D) . The following expression should be self explanatory if we take for the flow values s = s(p) and h = h(p). A_0 as the initial value of actual stocks, and D* the desired inventories.

$$\frac{dp}{dt} = -\lambda [A_0 - D^* + \int_0^t (s-h)dt]$$

(6)

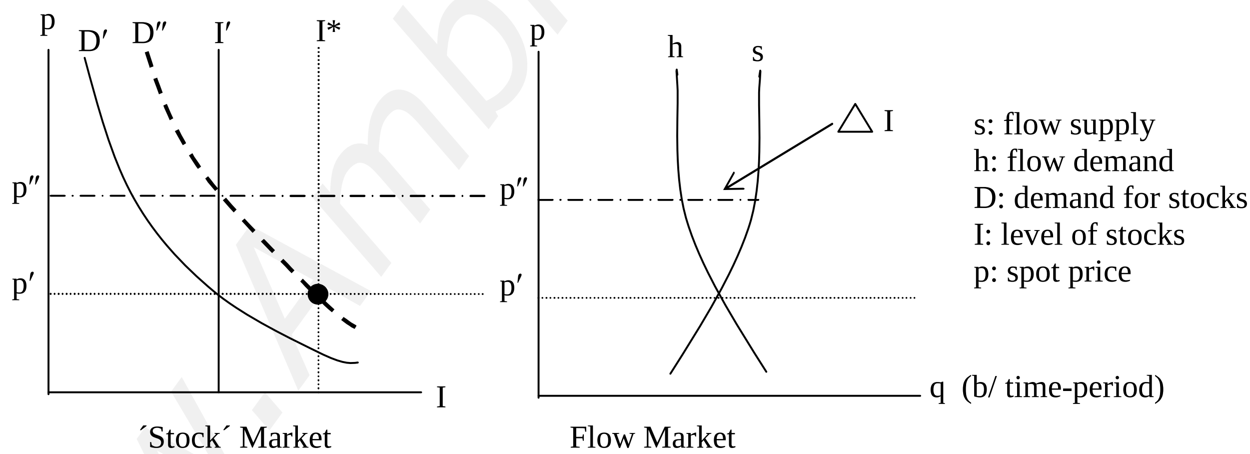
A differentiation of (1) with respect to ‘t’ will then immediately yield:

$$d^2p/dt^2 = -\ \lambda[\ s(p) - h(p)] \qquad (7)$$

What about a solution for this simple differential equation when s(p) and h(p) are made explicit? My answer on the present occasion is to compare it with the differential equations we might encounter in ballistics – for instance those for the trajectory of projectiles from mortars and recoilless rifles. These relationships are well known to interested students of analytic geometry and physics, and have been well confirmed experimentally. I know of no such confirmation for the price-time relationship that would result from a solution of equation (7), and if I heard of one I would not believe it.

In my lectures I invariably take linear equations for s(p) and h(p) – e.g. $s = s_0 + ap$ and $h = h_0 + bp$. These are of course approximations, and perhaps not very good approximations (except very close to the flow equilibrium). In addition, λ has to do with the ‘speed’ with which the (s – h) ‘gap’ is closed, but in *no* circumstances could *any* numerical value that we assigned be more than an approximation. What we are heading for here is a question as to the optimal scope of this exercise, and in my lectures this usually consists of writing out the relationship dp/dt = f(D – A), and comprehending its interior logic in terms of Figure 3 and Figure 4 below. As for (7), there might be some small utility in solving this simple second order differential equation and showing how the values of the parameters (e.g. a, b, λ) determine the stability of the price.

In order to complete this analysis, I add a more familiar stock-flow diagrams that tells essentially the same story as in Figure 3. Note that the initial stock equilibrium was at (I’,p’), and this was disturbed by an increase in demand for stocks (i.e. inventories). To obtain this increase price had to rise, perhaps to p”, but in any event it stayed above p’ – though not



<u>Figure 4</u>

perhaps at p” – until the new equilibrium at (I*,p’)

One of the reasons for not being more enthusiastic about the above mathematics is that I do not remember reading a great deal about gas inventories in those articles in the business press that are concerned with energy prices, which is a very different situation from the way that the inventories of oil and oil products (e.g. heating oil and gasoline) are treated. For instance, yesterday the oil price touched $96/b, and one of the explanations stressed expectations about inventories in the U.S. Whether this was an optimal explanation at the present time is quite another matter, however I can also point out that in any economics or finance course that I teach, Figure 3 makes an appearance, and I do not hesitate to make it clear that anyone who desires to pass any of these courses must be able to discuss the short term oil or gas price using Figure 3. As they once said in the American Navy, “on every ship there is someone who doesn’t get the message”, but this unambiguous message was inevitably understood by all of my students.

Something else that needs to be mentioned is that Figures 3 and 4 apply to the entire market. It would be difficult to argue that it was applicable for a single firm unless that firm was more than a price-taker and by itself could influence the price. But when on CNN or Fox News inventories of oil or gas are mentioned, it is made clear that the discussion concerns the market and not an individual firm.

Storage, Hubs and Market Centers

The natural gas production-consumption process begins with lifting of gas from a ‘field’ or ‘deposit’, and proceeds to a large diameter transmission or ‘merchant’ pipeline, with some gas siphoned off to ‘run’ the compressors, and usually some gas diverted from its ‘end-users’ or ‘final destination’ (i.e. households and small businesses) and into storage, further processing, and sale to very large consumers such as manufacturing industries and electric generators. Eventually it goes into distribution system where pipes are smaller, and via these pipes to homes and smaller commercial establishments, which are customarily designated ‘final consumers’. In Germany, in l995, there were many local distribution companies (LDCs), but since that country has no domestic gas production, the producing (i.e. wholesale) function is largely carried out by Holland, Norway and Russia. The following diagram summarizes this discussion.

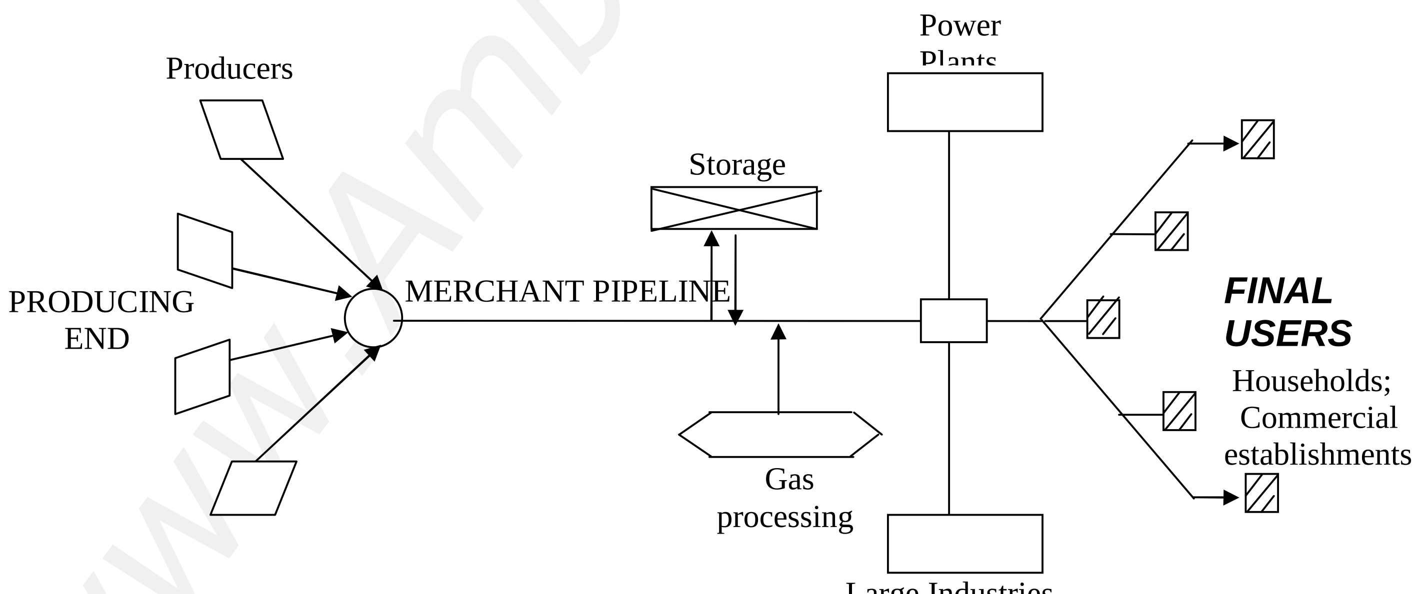


Figure 5

Storage is another of those subjects which submits to an interesting theoretical treatment, as you might notice in your book on operations research. On this occasion the exposition will be non-technical, although readers who want to impress others are advised to pay close attention to the terminology. Strangely enough, storage is almost completely ignored in microeconomics textbooks, despite the importance of its presence *or* absence: when it is absent prices often tend to be extremely volatile. Gas in storage is turning out to be a carefully watched statistic, particularly in the run-up to winter. Low storage levels mean that any shortages of gas that may appear during the coming months could impact on gas prices, as well as the availability (and price) of other fuels, such as heating oil. This is because certain other fuels are substitutes for gas in various uses. A short, easily read and valuable article on this subject is Van Atta (2007), published in one of the best energy forums, *EnergyPulse* (www.energypulse.net).

Just as transport involves moving a commodity through space, storage performs a similar function with respect to time – 'similar' but not identical, because time runs in only one direction. By putting goods into inventory, we move from the present to the future at finite cost, but returning the same goods to the present – and also recreating the background existing when the decision to store was made – is conceptually a much more difficult operation and, for the most part, impossible. This suggests that we have a *consistency* problem: at time 't' we make a plan for t+1, t+2,…, t+x,…,t+N, where N is the terminal date, but it might happen that at e.g. t+x, we perceive that the decision taken at 't' was sub-optimal. A new plan can then be put into practice, but conceivably we would have been happier if we had gotten things right in the first place, or formulated a strategy that would have taken into consideration the possibility of making expensive mistakes. This strategy might have featured storing more or less of the commodity, and relying more heavily on such things as futures and forward markets. Obtaining increased flexibility usually involves a cost.

An important and accessible article on storage is that of Benoit Esnault (2003), although it contains one implication that I have some difficulty accepting. This is that deregulation is a logical precursor to a decrease in prices and improvement in service. Such was the theory when electric deregulation was adopted, but if it is true that the ultimate object of deregulation was lower prices, then I take enormous pleasure in noting that electric deregulation has failed, is failing, or will fail just about everywhere. What we also have here – at least in some countries or localities – is a nice example of the consistency problem mentioned above. By that I mean the absence of a strategy for automatically reversing a sub-optimal venture (e.g. deregulation), and thereby mitigating the bad news that might unexpectedly appear.

A concept that is unique for storage is the *convenience* yield. This is explained in some detail in my first textbook (2000), but roughly it is the yield (i.e. gain) associated with greater flexibility that might devolve on the owners of inventories. For example, the availability of inventories permits output to be increased without incurring the expenses that are often unavoidable when it is necessary to resort to spot purchases in order to fulfil contract stipulations, or for that matter purchase futures or options contracts at prices that are regarded as unfavourable. The theory here is straightforward: an additional unit put into inventory can provide a sizable marginal convenience yield if inventories are small, while with very large inventories, the marginal convenience yield (associated with adding another unit) might be zero (although the convenience yield would still be positive and could be very large). In the simplest of cases inventory accumulation would continue until the cost of a marginal unit outweighed its marginal convenience yield, with both cost and yield measured in some convenient monetary unit. Another way of viewing this is to say that having access to storage encourages the transfer of consumption from periods in which its value is low to those periods when it is higher (e.g. *peak periods*).

In examining this issue, it can be argued that gas storage can not only moderate upward price movement, but also function as an excellent *hedge* against price and volume uncertainty. With natural gas – as with electricity – one of the key issues is *peak demand.* If a storage option is available, the exposition above indicates that gas is stored during off-peak periods and, if peak demand (or a 'glitch' of some sort in transmission or distribution) jeopardizes the ability to deliver desired quantities to end users, then gas is removed from storage. (Electricity cannot be stored, and so this procedure cannot be employed, but peak demand is satisfied by holding some equipment idle during off-peak hours.) An expression that might appear here is 'peak shaving', which sometimes brings a frown to the faces of energy economics students, but it means no more than releasing gas from storage into a pipeline during periods of maximum demand (i.e. peak periods). Possessing this option might make investment in additional producing or transmission capacity unnecessary.

Quality can also be brought into the storage picture. Depleted reservoirs are often used, but withdrawal is relatively slow from these structures. Salt caverns are better and allow rapid injections and withdrawal, which as Van Atta points out makes them attractive for traders who want to "capture value from price volatility". What this means is that when they have an opportunity to make some serious money, they do not want to be hindered by an inability to obtain the commodity that they are holding in storage and can be sold at premium prices.

Hubs are physical transfer points that are sometimes called 'pipeline interchanges'. They make it possible to redirect gas from one pipeline into another. However, at the present time, I prefer not to accept a recent report which claimed that spot prices at Henry Hub, which is one of the largest and best know gas market hubs in the world (and is close to the Lake Charles (Louisiana) LNG terminal) have assumed the role of international reference prices. This kind of claim is sometimes tied to the belief that a large expansion in the trade of liquefied natural gas (LNG) will eventually lead to an international market that is capable of replacing regional markets of one type or another. In the very long run, this hypothetical international gas market would comprise – via uniform net prices – both pipeline gas and LNG.

Even a survey of this length is not the place to speculate on a scheme of this nature, although if the demand for gas in the U.S. reaches the levels predicted by the U.S. Department of Energy, then it will mean that the movement of LNG toward the U.S. will increase to a point where there will be upward pressures on gas prices in every market. This is only the beginning. According to one prediction, China and India are expected to double their use of coal by 2030, and their combined oil imports are expected to surge from 5.4mb/d in 2006 to at least l9.1mb/d in 2030. To offset the environmental deterioration that this is liable to bring about, they will almost certainly be in the market for huge amounts of natural gas, and perhaps before reaching these estimated upper reaches, because in my opinion the oil production for 2030 that has been predicted by the IEA and the USDOE for 2030 cannot possibly be achieved.

In theory it might be desirable to combine hubs with market centers, where either of these might provide facilities that permit the buying and selling of services such as storage, brokering, insurance and wheeling – where *wheeling* means the provision of pure transportation services between external transactors. For pedagogical reasons, hubs are often portrayed as displaying a radial system of spokes (i.e. pipelines) and conceivably these spokes could be joined by adding short links.

Market centers are supposed to be able to operate independently of facilities for producing, transporting or storing the physical product, but even so, they should be able to provide a locale where shippers, traders, etc, can buy and sell transportation, gas, etc. To a certain extent the layout of these establishments could take on the structure of trading facilities in the financial markets. If there are imbalances anywhere, then in an 'ideal' market center there will be a mechanism where they can be located in a very short time rectified, which might include providing access to tradable pipeline space and also storage capacity. In the U.S. for example, market centers have direct access to almost 50% of *working gas* storage capacity and, in general, enjoy a special relationship with many of the high profile storage establishments. (Working gas is the amount of gas in a storage facility in excess of the ‘cushion’ or ‘base’ gas that is needed to maintain facility pressure and deliverability rates.) Regardless of the actual configuration, it is hard to avoid the conclusion that market centers will tend to form at, or in the vicinity of hubs, and that the number of arbitrage paths that can be utilized for obtaining uniform prices in a system are expanded if there is a proliferation of hubs, market centers and storage facilities.

Prelude to a Blunder

Since the publication of my gas book (1987), great changes have taken place in this market. The growth in the demand for gas exceeds that of all energy media except renewables, and unlike the situation 15 years ago, gas is highly recommended as an input for power generation. (In the UK, more than 70% of power is generated by gas or coal-fired power stations.) A main reason is the advent of *combined cycle* gas burning equipment with a very high efficiency. What happens here is that in addition to the gas turbine, there is a secondary turbine producing steam from the waste gases/heat of the gas turbine. The kinetic energy in this steam is transformed to mechanical energy that turns a generator. This generator produces additional electricity for a given input of gas.

However, as often happens, there are very many misconceptions in circulation about natural gas, the most pernicious of which – at least in Europe – have to do with its *restructuring* (i.e. deregulation/liberalization) of gas markets. Some question needs to be asked as to why and how these misconceptions came into existence, and it appears that the answer has to do with the very short time horizons of some producers, as well as the short time horizons and carelessness of consumers. In some parts of the world producers have expressed and conducted themselves in such a way as to suggest that there is virtually an infinite amount of natural gas reserves available for exploitation, when in many regions demand can only be satisfied by very large imports from distant sources. For instance, in much of the North America, exploration/production have been yielding disappointing results for a long time, and expectations about e.g. the Gulf of Mexico and imports by pipeline from Canada often have an air of unreality about them.

With certain exceptions, many gas buyers are almost totally unaware of how supply and demand could develop in even the present decade, and instead continue to make plans for a future in which they believe that they will have access to all the gas that they will need, at prices that resemble those of the recent past. This might be a good place to note that in Brazil, starry eyed deregulators counted on gas based electric power being cheaper than hydroelectricity. As they now admit, this incredibly *gauche* supposition was completely wrong.

According to the International Energy Agency (IEA) of the OECD, fossil fuels will account for 90% of the world primary energy mix by 2020, which is a big increase over 1997. Global gas demand is expected to rise by 2.5-2.7%/y, with the big consuming area being Asia, where it has been suggested that demand will increase by an average of 3.5%/y between 2001 and 2025. The share of gas in world energy demand could move in that period from 21% to at least 24%. (Oil’s *share* should fall, but this will be more than compensated for by the increase in world oil demand.) Another estimate has the average global gas production increasing by 2.75%/y to at least 2025, and gas passing coal as the second most important energy medium. Of course, the IEA could be mistaken. Their forecast for oil in 2030 is 120mb/d, which will only happen if production has peaked and is falling – which is not impossible.

World gas prices should eventually display an unambiguous upward trend. In picturing U.S. prices remaining flat until 2005, the IEA was clearly mistaken, but they are correct in noting that a tightening of U.S. and Canadian gas supplies is unavoidable, and this process could turn out to be very unpleasant. A wellhead price of $2.5/mBtu (in 1997 prices) for purely conventional US gas in 2020 did not seem particularly realistic to me when it was predicted, and if recent price movements continue, they could soon cancel out the favorable economics of gas-based power generation that resulted from advances in combined-cycle technology.

That brings us to the impact of liberalisation/restructuring. Here the IEA has mostly got it completely wrong on liberalisation in the electricity sector, and as a result I see no reason to expect an improvement in their ability to analyse the economics of world gas. However, since even the experts of the IEA are capable of comprehending that major uncertainties exist about the ability to develop and transport the more distant gas reserves, then it might be in order to suggest that considerable effort should be made to prevent the cavalcade of unsound ideas about deregulation/liberalisation from getting in the way of sound engineering practices. I think it useful to stress that the same exaggerated claims that were made for electric deregulation have also been made for gas, though not so aggressively as a decade ago.

To this it can be added that where gas reform is concerned, the economics debate is not particularly extensive, and in some cases is conducted by academic economists without the slightest feel for either the economics or the engineering aspects of the natural gas sector, and this includes economists with a modicum of engineering training in their background. They have not bothered to find out, for example, that an important component of the financial sector – in the form of several leading investment banks that are heavily involved with commodities – have scaled down their risk management commitments in some commodity markets. Warburg Dillon Read – the investment banking arm of UBS – closed down its energy and electricity derivatives business as early as 1999, and in the same year Merrill Lynch announced its withdrawal from over-the-counter derivatives in natural gas. While this was going on, a consensus of commodity traders and analysts were still willing to wager that derivatives activity in gas and electricity would take off once market liberalisation achieved a *critical mass*, and as it turned out, in electricity that condition was not too long in coming, although it did not turn out to be durable: it barely lasted long enough for the most important commodities exchange in the world (NYMEX) to declare its electricity futures contract hopeless, and also to cancel one of its natural gas contracts. (Let me note however that these contracts may already have been resuscitated. Wherever there are people who are sufficiently naïve to buy suspicious assets, those assets are certain to appear.)

Now for some particulars. Natural gas deregulation began in the U.S. about 20 years ago, and while I lose no opportunity to declare that I am an opponent of almost all electricity and natural gas deregulation, I remain sympathetic to the natural gas buyers and others in the US who felt that the regulatory climate at the time of the ‘gas bubble’ in that country did not correctly address either efficiency or equity concerns. What eventually happened though was that economists, consultants, and various ‘researchers’ were provided with a forum in which they could unleash a barrage of unscientific ideas for correcting what they construed as existing shortcomings, while at the same time promoting a radical transformation of the entire natural-gas sector – from ‘wellhead’ to ‘burner tip’. The first (non-technical) chapter of my new energy economics textbook attempts to convey some of the total lack of realism by deregulation enthusiasts.

How should we treat a collection of misjudgements of the magnitude and extent involved here. In my textbook, I did not treat them at all, because unlike the electric deregulation travesty, gas deregulation was never able to get up full steam. One of the reasons for this was that in the U.S., and perhaps elsewhere, some important politicians and industry people, as well as genuine experts from the academic world took issue with gas deregulation proposals. For instance, they pointed out that the natural gas market in the U.S. is *not* informationally efficient. This means that gas prices at widely separate localities do *not* follow each other in a manner which makes it possible to conclude that – when transportation costs are taken into consideration – these places are in *one* market, and thus the kind of arbitrage can take place which allows consumers faced with high prices to gain by buying in markets with lower prices. And not just in the U.S. A former CEO of British Gas went so far as to contend that the "half-baked fracturing" of the gas markets in order to bring about competition is essentially counter-productive, and a similar argument is apparent in the work of Philip Wright .

Someone else with an important observation on this topic is Professor David Teece of the University of California (1990). According to him, market liberalization in the U.S. has already "jeopardized long-term supply security and created certain inefficiencies." He also notes that "While more flexible, a series of end-to-end, short-term contracts are not a substitute for vertical integration, since the incentives of the parties are different and contract terms can be renegotiated at the time of contract renewable. There is no guarantee that contracting parties will be dealing with each other over the long term, and that specialized irreversible investments can be efficiently and competitively utilized."

I advise my student to not worry too much about guarantees where this topic is concerned in the context of the intentions of the Energy Directorate of the EU. For instance, assuming a 'path' (in e.g. the form of a pipeline) between two markets, and the cost of shipping gas is 'ρ' per unit, then prices (p) in these markets should lie within a distance 'ρ' of each other, or $d(p_1. p_2) \leq$ 'ρ'. If there are not paths, however, then at one time – and perhaps even today – the energy experts in the EU Energy Directorate expected billions of dollars to be invested in creating them, although the thinking here reduces to ideology and not economics or engineering.. This is why a colleague of mine in Milan once used the expression "Stalinist" to describe deregulation. Although the various misunderstandings about derivatives markets (e.g. futures and options) have always been fascinating to me as a teacher of economics and finance, they are paltry in comparison to uncertainties created by the transition from what some observers call 'planning' to what they interpret as the freedom of spot markets.

As far as I am concerned, large and complex gas systems operating in a climate of uncertainty are most efficiently run on an integrated basis that emphasises long-term contracting. *This kind of arrangement promotes optimally dimensioned installations, and although this may not be mentioned in your economics textbook, if pipeline-compressor-processing systems which fully exploit increasing returns to scale in order to obtain minimum costs are to be financed and constructed, then – as I interpret the evidence – the kind of uncertainties associated with short to medium term sales arrangements should be kept to a minimum. Failing to do so could cause a reduction in physical investment, and in the long run lead to higher rather than lower prices.* It was the proposed shift from bilateral transactions to spot markets that contributed to what is sometimes called *deregulatory uncertainty*, and a possible shortage in local (generator) capacity in the California and Alberta electricity markets. This, together with the move to deregulated *oligopolies*, was a principle determinant of the ruinous electric price rises faced by many households and firms in California, and perhaps elsewhere.

In Europe, the EU Commission initially mandated gas market restructuring by 2005. While I can imagine that they were sincere when they concocted this pipedream, I would be very surprised if they sincerely believe any longer that restructuring can or will be taken much further than liberalization, by which they mean that anyone, anywhere, should be able to buy anything that they can afford, and if this 'anything' is not for sale, then the rules should be changed so that it could eventually be put on the block. The rest of the restructuring/deregulation package – bringing into existence what they originally announced would be the kind of 'gas-to-gas' competition that is supposed to provide consumers with huge savings – will have to wait, and probably indefinitely. One of the reasons for this is almost certainly a morale problem among deregulation proponents due to the widespread failure of electricity deregulation, but another is the negative attitudes displayed by a number of high profile industrialists and important economists. An example of the latter is Mr Ron Hopper, who was with the U.S. government's Federal Energy Regulatory Commission (FERC) for 11 years, and as a private consultant was an advisor to the EU Energy Commissioner, and also the 'regulator' OFGAS (in the UK). Hopper calls himself a strong believer in deregulation, but even so he said that "It is difficult for me to see the potential for pipeline-to-pipeline competition" (1994).

Although I lack Hopper's insight in this subject, it is not "difficult" for me: it is impossible. I also have a problem comprehending why local distribution companies and consumers in the U.S. have been unable to understand that they might be forced to pay billions of dollars in transition costs in order to go from regulation to reregulation. Note: *not* in going from regulation to deregulation, but in going to a difference brand of regulation, at least for the foreseeable future!

To a certain extent, these payments were exactly what happened. Consumers and distribution companies (i.e. utilities) *were* burdened with higher costs, *and* found themselves assuming additional increments of the price risk that accompanied the various changes that were initiated. One of the reasons why things did – and were intended to – turn out this way is because, according to the deregulators and their academic booster club, consumers and distributors were going to be big winners once changes were installed, although this windfall might appear later rather than sooner. (This is also the kind of curious reasoning that the European Union movers and shakers specialize in.) As for the matter of *reliability*, this was simply overlooked or ignored, although as the leading business publication *Forbes* (Jan 22, 2001) intimated, deregulation has "whittled away" at the guarantee that many gas users had of a secure gas supply, since e.g. pipeline companies no longer had the incentive to resort to as much expensive underground gas storage as before, nor to use long-term contracts (with producers) to the same extent. Let me summarize the discussion above by saying that the talk about gas-on-gas or pipeline-to-pipeline competition in the face of external monopsony in Russia and perhaps elsewhere is sheer crank, at best.

To my way of thinking, the discussion above should be more than sufficient to convince alert readers and others that the corporations that have provided European consumers with plentiful supplies of low-cost natural gas for the last 3 or 4 decades should be allowed to carry on their business in the traditional manner. According to Tungland (1995), eccentric attempts to manipulate the laws of mainstream economics might prevent the mobilization of sufficient capital to realize economies of scale, and to shoulder the cost of projects with very long lead times. This was his response to Professor Peter Odell, who had somehow come to believe that such things as regulation and fragmentation could compensate for rising production costs and, apparently, a decline in the physical availability of gas and oil.

Russian Gas, and Some Comments on LNG

The production of energy is the moving force of world economic progress.

-Vladimir Putin

A few weeks before this paper was completed, Professor Jonathan Stern visited the Stockholm School of Economics, where he presented a ‘pop’ version of Russian gas intentions in both their own country and regions west of the Russian border. So many dubious statements were launched during that session, and apparently accepted, that I found myself painfully aware once more of the macroeconomic and political catastrophe that may someday arrive because of a sudden and pervasive shortage of energy – a condition that to a considerable extent is due to the grotesque deficiency that has marked the teaching of energy economics over the last decade.

One of the items in my gas book that apparently kept it from a prominent position on the favourite bookshelf of certain gas experts was my contention that while the U.S. and most of the states of Western Europe were political allies, they were also economic rivals. One person who apparently had some difficulty with this concept was former U.S. president Ronald Reagan, whose experts informed him that instead of buying gas from the Soviet Union, his European comrades-in-arms should make some effort to obtain the supplies they required from e.g. Africa and Argentina, because by doing so it would weaken the Soviet economy. Needless to say, the chief executive was constitutionally unable to accept the most sensible strategy, which was to contract for the largest possible quantities that could be obtained from the Soviet Union, and to encourage that country to invest in (and fill) the largest possible pipelines. The basic issue was not merely safeguarding and expanding Western Europe’s supplies of gas in the years to come, but increasing the availability of all energy materials that were being purchased by the United States, as well as some that were not. (Another of President Reagan’s theories apparently was that a return of the Taliban to Afghanistan was greatly desirable and should be expedited. I would like to go on record as saying that the war that is now going on in that part of the world could be in full swing when the New Year’e eve parties begin to celebrate the beginning of the 22nd Century.)

When I pointed out the advantages of doing business with Russia in a talk at Cambridge University, a number of observers – to include the founder of the influential publication *Geopolitics of Energy*, Melvin A. Conant – assured me and everyone else present that although the ideological commitment of the Soviet Politburo was ostensibly to Marx and Lenin, it was equally to dollars and deutschmarks, which made executives in the Soviet gas industry prone to discharge their business obligations. If we can assume that there is no change in this posture, then it might be useful to examine the proposals of Claude Mandil – executive director of the International Energy Agency (IEA) of the OECD – which are aimed at preventing what he views as a potential supply gap whose closing will take “money and time”.

Given that he estimates that it will require only 11 billion dollars per year to finance the investment required so that announced Russian production and export goals can be met, the key issue appears to be time, because it should be possible to obtain the cash involved by just passing the hat at an ad-hoc photo-op arranged for the most presentable billionaires in a recent *Forbes* listing (March 27, 2006).

My assumption is that this 11 billion would actually go to the production and transportation of gas, rather than things like junkets to wonderful Courchevel or gorgeous ‘Kitz’ at the height of the skiing season, as Mr Mandil (and some others) have indirectly implied. Personally, I believe that the Russian firm Gazprom was correct in dismissing this aspersion. They would also be correct in ignoring Mr Mandil’s suggestion that the Russians should provide “real third-party access” to gas pipelines, since the expression “third-party” insinuates foreigners interfering with matters that they are completely incapable of understanding. I can also mention that 11 billion does not sound right to me, and something else that does not sound right is the delay in the construction of new pipelines from Russia such as *Nord Stream* (through the Baltic). This delay is partially due to some strange ideas in Sweden as to the ulterior purposes of the Russians (when actually what it probably means is a financially advantageous arrangement of some sort between the Russians and Germans and perhaps the Dutch). What is also not understood in Sweden is that the more Russian gas that comes into Western Europe, the lower will be the price of electricity in Sweden – a price that has been boosted by the absurd electric deregulation encouraged by the European Union as well as the sale of electricity on the electricity exchange NORDPOOL, which is both a 'scam' and what George Orwell might have called an indoor welfare scheme.

A year ago the kingpins of the European Union (EU) held a meeting at which the availability of Russian natural gas and oil was discussed at length, and none other than the *Financial Times* (March 23, 2006) suggested that the sale of Russian gas to China and Japan might have a negative effect on the energy prospects of Europe, which relies on Russia for 70% of its gas. By extension, in the long run, this could have a negative effect on North America, because the global gas scene has begun to take on some of the features of a mainstream textbook market. Of course, it could never take on all the attributes because – as pointed out in the later chapters of your favourite volume on price theory – a 'natural' monopoly or monopsony in natural gas has too many special features to end up with a perfectly competitive configuration. An important natural monopsony that can be cited here is the one that Gazprom enjoys vis-à-vis countries like Turkmenistan and Uzbekistan. Gazprom obtains inexpensive gas which can be sold at a higher price in Europe. What operations like this are doing is providing Russia with the wherewithal to rediscover its superpower status. Russian oil and gas revenues have quadrupled over the period 1998-2006, and revenues this year should reach a higher level than any of those years.

According to Claude Mandil, gas import dependence for the 25 EU members will grow from just under 50 percent to 80 percent (which says something about the expected decline of output in the North Sea), while in North America, the present small level of imports will reach 14 percent (*FT*, 23 March). Even so, he has apparently been informed by somebody that there will be a significant displacement from the past three decades when the OECD accounted for the majority of new energy demand: now he sees developing countries dominating the energy growth picture. Mandil also confirms that the import reliance of Japan and Korea will remain very high, while China and India will emerge as "big gas importers". How big? This he doesn't reveal, although I feel sure that his experts have provided him with some guidelines. In case they provided him with the wrong ones, let me suggest that the effective demand of these two giants is potentially large enough to cut the ground out from under the international macroeconomy. (By "effective" I mean that they can pay for any purchases they make with hard currency.) Anyone doubting this should schedule a heart-to-heart with the former boss of the Federal Reserve System Alan Greenspan before he loses interest in these matters.

Among other things, Greenspan has flatly stated that the war in Iraq is about oil. In the present context this means that the decision makers in Washington (and perhaps elsewhere) no longer believe the high ranking academic at New York University who said that the oil price would not rise by much over $20/b, because among other things it would be possible to produce a synthetic commodity from gas. Generically, the process involved was called gas-to-liquids (GTL), but much less is heard about it at the present time than a few years ago. In addition, given that OPEC countries made approximately 650 billion dollars from oil sales in 2006 as compared to 110 billion in l998, it seems unlikely that they will have a problem financing a large part of the GTL plants that our energy economics scholar expected to surface in the gas-rich Middle Eastern OPEC countries, and whose output will *not* be sold at bargain basement prices. Something that readers should understand at this point is that these plants will produce both motor fuels and naptha, where the latter is an important input for petrochemicals, and also clean-burning diesel fuel. According to the development economics that I taught in Dakar many years ago, petrochemicals could play a major role in the industrialization that has begun in the OPEC countries in the Middle East.

Something else that we do not hear much about is a possible participation of the Russians in the growing supply of liquefied natural gas (LNG), although that option has been raised by some observers. There has also been a modicum of talk about Russian gas exports from the new Sakhalin LNG scheme gaining access to Asia-Pacific markets, which could include utilizing terminals opening in India, which is possible but not certain, however it is interesting to note that the Russians decided to develop the giant gas field Shtokman without foreign help, and switch it from a source of LNG for the U.S. to a pipeline venture whose gas is destined for Europe.

In theory there should be a place for Russian LNG in the U.S., because while LNG accounts for only about 2% of the gas used by the U.S. at the present time, the United States Department of Energy (USDOE) has suggested that it could amount to 30% by 2025, with the total demand for gas in the U.S. amounting to about 30 trillion cubic feet. As Mark G. Papa, an important American energy executive has said, “Right now, on the supply side, LNG is the only lever we have to pull”. One of the problems in the U.S. (and probably elsewhere) is the shortage of terminals that can receive gas from ships, and after regasification direct it into the domestic pipeline system. Moreover, many Americans to not want LNG plants in or near where they live. After an accidnet in Algeria reminded environmentalists that LNG (because of its density) has a very large explosive potential, they informed the general public that LNG might prove to be an attractive target for terrorists. California is a state where the opposition to new terminals is very strong and growing, and as a result the next terminal serving consumers in that state will likely be in Mexico (to be exact *Baja California*), and probably within easy driving distance of San Diego.

Given the subject of this presentation, it seems proper to remind readers of the steps in the obtaining by households, small commercial establishments, power generators and heavy industries of conventional gas that at one point was LNG.

The first step is production in the manner described in several places above. Next liquefaction, where the gas is chilled and compressed in a manner so that $600ft^3$ of gas becomes one cubic foot of liquid. After that this liquid is shipped in special vessels, and when it reaches the country in which it is to be used it is regasified. It can then be put into conventional gas pipelines and moved to buyers. It also happens that in the last decade or two costs have been greatly reduced by economies of scale and technological advances, especially in liquefaction. As with pipelines and compressors, the larger the units the greater the cost efficiencies – up to a certain point.

LNG plants have been constructed in the fairly recent past in Nigeria, Australia, Qatar, and Trinidad, and eventually Iran should become a major supplier. In the last five years LNG has grown by almost fifty percent, but apparently demand is still greater than supply. Rumor has it that foreign firms do not want to invest in Iran because it may someday be visited by U.S. bombers, but if bombs begin to fall on that country the price of oil could move off the Richter scale. Besides, with the oil price at its present level, and with the technical ability possessed by Iranian citizens, foreign investment is an option that is far from essential. Algeria was the first country to ship LNG, while Qatar has displaced Indonesia as the world’s largest LNG exporter.

According to the *Financial Times* (October 20, 2006), Qatar exports LNG to the U.S. on short term contracts. Why short-term? The answer of course is that they expect the price of gas to increase, and in addition they and their colleagues in the Gulf can make a reality of this expectation. The IEA has predicted that before the next decade is over, LNG will account for up to 16 percent of the global demand for natural gas, and there has been some talk recently of the possibility of a gas producers' organization along the lines of OPEC. Someone who disagrees with this is David Victor of Stanford University, but I have made a point of discounting Mr Victor's argument on this subject, and say that there is a finite probability that we could see a producer's organization for gas some day. I doubt though whether that probability has reached 50%.

The *Financial Times* has also stated that Qatar intends for its natural resources to benefit that country for the next 100 years. 100 is a nice round number, but if Qatar is serious and the other Gulf countries join them in this agenda, then it is a certain that the period of low energy prices is over for a long time – until nuclear and certain renewables play a much greater part in the scheme of things than at the present time.

Final Remarks and Conclusions

One of the major themes of this paper is the possible scarcity and rise in price of natural gas, given the rapidly increasing demand for this commodity. On many occasions and in many places I have delivered aggressive harangues about oil, and the gradual approach of oil to a price of \$100/b seems to have confirmed my predictions. When Armand Hammar of Occidental Oil said that this would be the price at the end of the 20th century, he was judged to have gone off the deep end, but now we are almost there, and 'anomalous' events are always possible that could make \$100/b appear attractive.

I can remember encounters with persons who were not impressed with my scholarship, and who informed me that new technologies and knowledge ensure that tolerating and adjusting to high-price oil is always possible, and in the short run. Originally teachers of economics and finance like myself thought that oil at the present price would trigger a macroeconomic disaster, but this has not happened, and so I am just going to mention – *en passant* – why. The negative effect of this destructive oil price has been lessened by large scale immigration to most of the main oil importing countries, as well as some related changes in income distribution in those countries. As an exercise, concerned readers can elaborate on this statement, and perhaps at the same time attempt to figure out exactly how long this situation will prevail – assuming that they believe that I am correct. Furthermore, the high oil price will pull up the gas price, and if the financial market continue to deteriorate, then it will be very difficult to avoid a crisis. Incidentally, the most peculiar aspect of the run-up to this crisis has been the large-scale creation of sub-prime financial assets, and their purchase by some of the largest and most important financial institutions in the world, with perhaps the most sophisticated research departments. What this means to me is that someday readers of this article may have a place doing research for those establishments.

In my earlier energy economics textbook I presented a heuristic derivation of an equation whose purpose was to show an aspect of the scarcity of oil. It applies only marginally to gas, but several of my students in Bangkok seemed to prefer a systematic derivation. This will be provided below, beginning with an expression for the quantity of reserves (Q) that will be available at time T. 'q' is the production of gas, and X the increase in reserves during a given period due to e.g. exploration. Q(0) is reserves at time '0' and q(0) production at the same time..

$$Q(T) = Q(0) - \int_0^T q(0)e^{nt}dt + \int_0^T X(t)dt \qquad (8)$$

Notice that $q(0)e^{nt} = q(t)$, where n is the constant or trend rate of growth of production. I also assume a constant rate of growth of reserves, g, and thus we have g = X(t)/Q(t). This can be verified by differentiation. By using this expression and dividing (8) by q(T) we get and expression for the reserve-production ratio 'Z', which for T is:

$$Z(T) = Q(T)/q(T) = \frac{Q(0)}{q(T)} - \frac{1}{q(T)}\int_0^T q(t)dt + \frac{1}{q(T)}\int_0^T gQ(t)dt \qquad (9)$$

Next, observing that $q(T) = q(0)e^{nt}$, and thus we get via differentiation the expression q'(T) = nq(T), we can differentiate (9) with respect to T to get:

$$dZ/dT = -\frac{nQ(0)}{q(T)} + \frac{n}{q(T)}\int q(t)dt - \frac{1}{q(T)}q(T) - \frac{n}{q(T)}\int_0^T gQ(t)dt + \frac{1}{q(T)}gQ(T) \qquad (10)$$

This can be simplified right away to dZ/dT = (g – n)Z(T) – 1. The interpretation here is revealing. Assume for example that n = 0 and g = 5 percent, where reserve growth is measured from the beginning of the year. Intuitively we might jump to the conclusion that Z is growing, but this need not be so. In fact, what is being said here is that for Z to be increasing, it must be greater than 20 at time T. Just how can this be so?

The answer is that in this exercise the growth of reserves is measured from the amount existing at the beginning of each year. For example, if reserves at the beginning of the year are 150, and the annual reserve growth is 5%, then reserves increase by 7.5. But reserves at the end of the period are not 150 + 7.5 but 150 + 7.5 minus production for that year. Thus, as indicated in the algebra, for total reserves to expand over time, reserve additions must be large relative to consumption.

With electricity deregulation (i.e. *restructuring*) obviously imploding in many countries or regions, it might be pertinent to focus on those aspects of the electricity story that are most relevant for gas. As already noted, first and foremost we should make certain that EVERYBODY understands that *restructuring increases uncertainty, and (ceteris paribus) uncertainty decreases physical investment*. This is a straightforward neo-classical result, and from the point of view of common sense as well as mainstream economic theory, it makes all the sense in the world. At one time in Europe it appeared that deregulation carelessly mixed with bureaucratic blundering was a far greater danger with electricity than with gas, given that the EU movers and shakers wanted enough investment to take place to avoid a California type situation. But now virtually every intelligent observer realizes that electric deregulation is *passé*.

Moreover, in Europe and perhaps elsewhere, restructuring means that a competitive or partially competitive gas purchasing structure could find itself confronted by powerful external suppliers operating in a monopolistic or oligopolistic mode. Thus the already high price of gas could go higher, to the detriment of large firms as well as households and small businesses. In the US both former Energy Secretary Spencer Abraham and former Federal Reserve Chairman Alan Greenspan have expressed concern about the present development of natural gas prices, which on more than one occasion they have pictured as a threat to the U.S. economy on the same plane as an escalation in oil prices.

Put more directly, it might have been a mistake to become so thoroughly attracted to natural gas. A good example here is the situation in e.g. California, where more than 80% of new capacity was fired with gas. Moreover, faith in the availability of gas appears to have been so extensive that a large percentage of the new gas-based power plants lacked fuel-switching capacity, and it unfortunately seems that the older facilities with a fuel switching option were, on the average, less efficient. Accordingly, the efficiency and versatility of the entire system is considerably less than it should be – and would have been – had the deregulation advocates been kept in their place.

I find it stimulating to report that the majority of energy professionals are coming to their senses where the above topic is concerned, and as icing on the cake, considerably less tolerance is being shown the ravings of flat-earth economists and their adherents where future supplies of gas and oil are concerned. What is happening is that these ladies and gentlemen have started paying closer attention to reality than to the kind of bizarre economic theory that became popular in the U.S. during the presidency of Ronald Reagan and his guru Professor Milton Friedman, who at one time thought that the oil price would descend to $5/b. The domestic U.S. gas output has peaked, and d alarmingly the gas rig count in that country also appears to have peaked. This suggests that more than a few important firms now regard that region a hopeless case for large scale future investment, even if prices continue to rise. Furthermore, as in the U.S., increased drilling in Canada is not raising production by a substantial amount. The situation in both countries can easily be summed up as follows: mature basins, smaller discoveries, and a high rate of natural decline from existing gas wells – which unavoidably translates into higher energy costs.

As alluded to earlier, Mexico is not going to provide much help to U.S. gas consumers. Mexico is slowly but surely being transformed into a large importer of gas. Something worth emphasizing is that even if a substantial Canadian export capacity became available, in order to provide large amounts of gas to the US, very expensive pipelines would have to be constructed. I have also heard it argued that increased drilling in traditional gas producing regions in Canada is not increasing production by the expected amount, and in the Western Canada Sedimentary Basin (WCSB), production from gas wells – on the average – has been declining at almost 6%/year for the last nine years. It may also be true that in Canada, as in the US, large producers are more likely to busy themselves with cost reducing mergers rather than devoting scarce time and money to expensive investments in new capacity. The managers of these enterprises learned long ago that large fields take a long time to develop, which is something that is often overlooked by those journalists whose attention is usually concentrated on listed reserves, and at the same time believe that a *flow* from a *stock* of reserves can be obtained in no more time than it takes to manipulate supply curves in textbook presentations.

What some observers might have overlooked – deliberately or otherwise – is that the natural gas industry is inherently less flexible than e.g. the electricity industry. Because the electricity sector is subject to Kirchoff's laws, many students of deregulation think that is easier to control flows in the gas sector, and thus bring about the amount of network price adjustments required to obtain (via arbitrage) the utopian results promised by the deregulators. As mentioned earlier, spot prices at widely separated points in large gas networks are not related to each other in such a way that it is possible to claim that they are in one market, and this is largely due to coordination problems that are almost unavoidable due to erratic shifts in the demand for gas. In addition, time lags are unavoidable in scheduling deliveries, which results in a sub-optimal use of storage and transmission capacity that is further distinguished by the frequent appearance of transactional bottlenecks. Deregulation is not likely to improve this situation. Even the electricity market is more accommodating when it comes to avoiding 'glitches' of this nature.

In selling electricity and gas deregulation to the voters, among the pseudo-scientific arguments first employed were that increasing returns to scale were a thing of the past. A competent teacher of economics or engineering should be able to expose this myth in a half-hour by employing some secondary-school algebra or 'soup-bowl' type cost diagrams to interpret the relationship between the expected growth rates of gas and electricity consumption, and the incentive to take advantage of scale economies (or *sub-additivity*) of the relevant cost functions. Accordingly, one way in which this matter was approached was to complicate it by claiming that sub-additivity was absent in these industries, and thus introducing into the discussion technical matters that most readers took considerable pains to avoid. As it happens though, the relevant materials on sub-additivity (or increasing returns to scale) are easy to locate in the intermediate economics literature, and equally as easy to comprehend. Another way of approaching this issue is merely to ask managers and engineers in the gas (and electricity) industries whether they believe in the non-existence of increasing returns to scale.

John Stuart Mill, in his *Principles of Political Ec*onomy (written in l848), remarks that "the laws and conditions of production partake of physical truths. There is nothing arbitrary about them." Except, to partially quote US Congressman Peter de Fazio, when we are dealing with people "who are going to make millions and billions". These are persons willing to do and say anything that will convince the consumers and businesses on the buy side of gas and electricity markets that restructuring will enable them to make hundreds and thousands. This happened in Sweden where deregulation allowed power firms to invest in existing foreign generating capacity rather than new domestic facilities.

Regardless of how we approach oil-gas-electricity markets, we inevitably see conduct which suggests that we do not have the perfectly (or even *partially*) rational transactors mentioned in your favorite economics textbook. In New Zealand, as elsewhere, there are a number of theories about what went or is going wrong with the domestic energy supply. The simple truth is that nothing has gone wrong; globally, oil and gas have become scarcer, and the consequences are that in most countries consumers and producers will just have to learn to transact their business against that unpleasant background instead of the make-believe world of infinite supplies of energy that they were promised by the flat-earth economists. When I first worked in Australia, the giant Maui gas field in New Zealand was considered a priceless asset, and virtually nobody took the trouble to think of it as having a finite 'lifespan'. Now it is in sharp decline, with apparently only a few years' of what are sometimes called 'recoverable' reserves left., by which it is evidently meant reserves that can continue to supply gas at the production levels of a decade ago.

I can begin closing this long survey by suggesting that an understanding of the political and economic circumstances of that New Zealand gas decline would provide a valuable intellectual experience for anybody believing that even today we are running 'into' rather than out of oil and gas. These pseudo-scholars and amateur researchers are making a dismal contribution to the traumatic situation that could occur should global oil and gas production unexpectedly begin to level off.

I also want to note that there are journalists, academics and assorted paid and unpaid propagandists who have decided to inform everyone in their 'network' that the high oil and gas prices now being experienced are irrelevant from a macroeconomic and financial market point of view: ostensibly, today's economies have become so sophisticated when it comes to saving energy that oil prices above $70/b, and corresponding gas prices, do not pose any threat to macroeconomic stability.

Regardless of its source, I think that it is best to disregard this kind of twisted wisdom. In the conference of EU movers-and-shakers referred to in this paper, it was proposed that the EU countries should formulate a joint strategy for dealing with their energy vulnerabilities. I can sympathise with this to a certain extent, although I fail to see how this suggestion ties in with the deregulation nonsense that was launched by the EU Energy Directorate. The commander of the EU Energy Army is a man who believes that 'peak oil' is only a theory, and even worse, has announced that electric and gas deregulation is a goal worth pursuing. Accordingly, I think that we would all be better off if we ignore his precious knowledge until he absorbs the lessons of economic history, and learns enough economic theory to distinguish sense from senselessness.

References

Angelier, Jean-Pierre (1994). *Le Gaz Naturel*. Paris: Economica

Asche, Frank, Petter Osmundsen and Ragnar Tveterås (2000). 'European market Integration for gas'. Working paper series: CESifo, Munich.

Bahgat, Gawdat (2001). 'The geopolitics of natural gas in Asia,' *The OPEC Review*, (30)3:275-290.

Banks, Ferdinand E. (2007). *The Political Economy of World Energy: An Introductory Textbook.* London, Singapore and New York: World Scientific.

______ (2004). 'An introduction to the economics of natural gas'. *OPEC Review (*March*)*. 24-38.

______ (2000). *Energy Economics: A Modern Introduction*.Boston,Dordrecht, and London: Kluwer Academic Publications

______ ´(1987) *The Political Economy of Natural Gas*. London and Sydney: Croom Helm.

Bers, Lipman (1976). *Calculus*. New York and Chicago: Holt, Rineheart and Winston.

Chew, Ken (2003). 'The world's gas resources'. *Petroleum Economist*.

Commichau, Axel (1994). 'Natural gas supply options for Europé – are distant supplies affordable?' *The Opec Bulletin* (May).

Corzine, Robert (1999). 'Battle with gas gets underway,' *The Financial Times*, Sept. 23.

Dahl, Carol A. (2004). *International Energy Markets*. Tulsa: PennWell Books.

Darley, Julian (2004). *High Noon for Natural gas*. London: Chelsea Green.

DeVany, Arthur S. and Walls, W. David (1995). *The Emerging New Order in Natural Gas*. Westport Connecticut: Quorum Books.

Esnault, Benoit (2003). 'The need for regulation of gas storage: the case of France'- *Energy Policy* (167-174).

Dispenza, Domenico (1995). 'Europé's need for gas imports destined to grow,' *Oil and Gas Journal*, March 13.

Happel, J. and Jordan, D. (1975). '*Chemical Process Economics'*. New York: M. Dekker.

Hawdon, David and Nicola Stevens (1999). 'Regulatory reform in the UK gas market – the case of the storage auction,' Surrey Energy Economics Centre.

Hodges, R.E. (1985). P.C. program selects gas-line sizes. *Oil and Gas Journal* (April).

Hopper, R. (1994). 'Open access in Europe.' *The Financial Times Energy Economist*: 147-151.

Hotelling, H. (1931). 'The economics of exhaustible resources'. *Journal of Political Economy*. 39:2

Paulette, C.H. (1968). 'A new approach to use of the revised panhandle formula'. The *Pipeline Engineer* (March).

Späth, Franz (1983). 'Die preisbildung für Erdgas.' *Zeitschrift für Energiewirtschaft* (3)4:99-101.

Teece, David J. (1990). 'Structure and organization in the natural gas industry'. *The Energy Journal*. 11(3):1-35.

Tungland, K. (1995). 'Comment on Odell.' *Energy Studies Review*.

Van Atta, Lee (2007). 'Natural gas storage takes off on volatility.' *EnergyPulse*

(www.energypulse.net).
Wright, P. (2005). 'Liberalisation and the security of gas supply in the UK.' *Energy Policy*

Uppsala, Sweden: November 11, 2007